National Exams May 2015

98-Pet-B2, Natural Gas Engineering

3 hours duration

NOTES:

1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.

2. This is a CLOSED BOOK exam.

3. Any non-communicating calculator is permitted.

4. FIVE (5) questions constitute a complete exam paper.

5. The first five questions as they appear in the answer book will be marked.

6. All questions are of equal value unless otherwise stated and all parts in a multipart question have equal weight.

7. Clarity and organization of your answers are important, clearly explain your logic.

8. Pay close attention to units, some questions involve oilfield units, and these should be answered in the field units. Questions that are set in other units should be answered in the corresponding units.

9. A formula sheet is provided at the end of questions
Question 1 (20 Marks)
Explain (briefly in one or two sentences) the following concepts.

a) Dry gas  
b) Cricondenbar  
c) Water content  
d) Volumetric gas reservoir  
e) Pigging operation  
f) Gas formation volume factor  
g) Well deliverability  
h) Acid gas  
i) Sour gas  
j) Orifice meter

Question 2 (20 Marks)
A gas well is producing dry natural gas at a flow rate of 10 MMSCFD with the following well stream composition:

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole Fraction</th>
<th>Molecular Weight (lbmole/lbmoles)</th>
<th>Pci (psia)</th>
<th>Tci (°R)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methane</td>
<td>0.92</td>
<td>16.04</td>
<td>666.4</td>
<td>343.33</td>
</tr>
<tr>
<td>Ethane</td>
<td>0.05</td>
<td>30.07</td>
<td>706.5</td>
<td>549.92</td>
</tr>
<tr>
<td>Propane</td>
<td>0.03</td>
<td>44.11</td>
<td>616.4</td>
<td>666.06</td>
</tr>
</tbody>
</table>

The gas well is flowing to the production facility using a flow line with an internal diameter of diameter of 4 inches and an average pressure and temperature are 2500 psia and 120 degree C, respectively. Calculate the average gas velocity inside the flow line in ft/sec.

Question 3 (20 Marks)
As a part of a gas injection project, produced natural gas with a specific gravity of 0.68 from a separation facility needs to be transported to another station located 20 km far from the gas production facility. The separation facility operating pressure and temperature are 1500 psia and 77 °F, respectively. Determine the diameter of the transportation line to handle gas flow rate of 220 MMSCFD and a delivery pressure of 1000 psia. Assume a pipe roughness of 0.0012 ft, an average viscosity of 0.015 cP, and an average gas compressibility factor of 0.85 for the natural gas. Show one step of your detailed calculations toward the solution.
Question 4 (20 Marks)
Natural log (ln) of gas production rate versus cumulative production rate available from a volumetric dry gas field producing under the boundary-dominated flow condition is given in the following. Note: unit for q in this plot is MSCFD.

a) How long does it take to produce 2 MMMSCF of natural gas from this reservoir?
b) Calculate gas reserves if a minimum rate limit of 100 MSCFD is allowed for the gas field.

Question 5 (20 Marks)
A gas well is open to production at a rate of 7 MMMSCF for 36 hr. At this time the rate is increased to 21 MMMSCF for 72 hr (108 hr total production time for production). Use reservoir data and the real gas pseudo pressure plot given in the following to calculate well pressure after 108 hr of production of this well. Assume infinite acting behaviour.

Initial pressure, $p_i$ 2000 psia;
Reservoir Temperature, $T$ 580°F;
Formation thickness, $h$ 39 ft;
Gas viscosity, $\mu$ 0.0158 cP;
Porosity, $\phi$ 0.15;
Permeability, $k$ 20 mD;
Well radius, $r_w$ 0.4 ft;
Gas isothermal compressibility, $c_i$ 0.00053 psi$^{-1}$. 
Question 6 (20 Marks)
Two separate flow tests have been conducted in a gas well and the following data has been obtained after interpretation of the tests.

<table>
<thead>
<tr>
<th>Test #</th>
<th>Rate (MMSCFD)</th>
<th>Skin factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>+1</td>
</tr>
<tr>
<td>2</td>
<td>50</td>
<td>+3</td>
</tr>
</tbody>
</table>

Calculate the true skin factor and the non-Darcy (the turbulent flow factor), D. Do you recommend acidizing this gas well? Explain your results.
Question 7 (20 Marks)
A back pressure test has been conducted to determine the well deliverability. The following flow rate and bottom-hole pressure information was obtained from the test.

<table>
<thead>
<tr>
<th>Flow period</th>
<th>Rate (MMSCFD)</th>
<th>Bottom hole flowing wellbore pressure (psia)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shut-in</td>
<td>0</td>
<td>3884 (Average Reservoir Pressure)</td>
</tr>
<tr>
<td>1</td>
<td>2.19</td>
<td>3387</td>
</tr>
<tr>
<td>2</td>
<td>2.57</td>
<td>3268</td>
</tr>
<tr>
<td>3</td>
<td>3.16</td>
<td>3092</td>
</tr>
<tr>
<td>4</td>
<td>3.40</td>
<td>3015</td>
</tr>
</tbody>
</table>

Use the log-log chart given in the following to estimate the well deliverability at a bottom hole flowing pressure of 2500 psia.
Gas properties:
\[ M_a = \sum y_i M_i, \quad \text{where } y \text{ is mole fraction and } M \text{ is molecular weight in lbmass/lbmole,} \]
\[ \gamma_e = \frac{M_a}{M_{air}}, \quad \gamma_g \text{ is gas specific gravity (Air=1)}, \]
\[ T_{pc} = 169.2 + 349.5 \gamma_g - 74.0 \gamma_g^2, \quad T_{pc} \text{ is the pseudo critical temperature}, \]
\[ p_{pc} = 756.8 - 131.0 \gamma_g - 3.6 \gamma_g^2, \quad p_{pc} \text{ is the pseudo critical pressure}, \]
Correction for N₂, H₂S, and CO₂: \[ T'_{pc} = T_{pc} - 80y_{CO_2} + 130y_{H_2S} - 250y_{N_2} \]
Correction for N₂, H₂S, and CO₂: \[ p'_{pc} = p_{pc} + 440y_{CO_2} + 600y_{H_2S} - 170y_{N_2} \]
\[ T_r = \frac{T}{T_{pc}}, \quad p_r = \frac{p}{p_{pc}} \]
\( T_r \) and \( p_r \) are reduced pseudo critical temperature and pressure, respectively.
\[ \rho = \frac{pM}{ZRT} \quad \text{where } \rho \text{ is gas density in lbmass/ft}^3, \quad p \text{ in psia, } T \text{ in R, } M \text{ in lbmass/lbmole, } R=10.732 \]
\[ \text{psi-ft}^3/(\text{lbmol-°R}) \]
Gas formation volume factor, \( B_g = 0.02827 \frac{ZT}{p} \text{ in } \frac{\text{ft}^3}{\text{SCF}}, \text{ where } p \text{ in psia, } T \text{ in °R}. \]
Standard condition: \( T_{sc}=60 \degree \text{F, } p_{sc}=14.7 \text{ psia.} \)

Pipeline flow capacity equations:
\[ q_{sc} = 5.634 \left( \frac{T_{sc}}{p_{sc}} \right) \left( \frac{p_{sc}^2 - p_1^2}{\gamma_g} \right)^{1/2} \left( \frac{L}{g} \right)^{1/2} \left( \frac{d}{2} \right)^{5/2} \text{ where } T \text{ in °R, } d \text{ in inch, } L \text{ in ft, } q \text{ in MSCFD.} \]
\[ N_{Re} = 710.39 \frac{p_{sc} \gamma_g g_{sc}}{T_{sc} \mu d} q \text{ in MSCFD, viscosity in cP, } d \text{ in inches.} \]

Decline curve analysis
Exponential decline: \( q = q_i e^{-D t} \),
Harmonic decline: \( q = q_i (1 + D t) \)
Hyperbolic decline \( q = q_i (1 + b D t)^{-1/b} \)
Cumulative production \( G_p = \int q dt \)
\( G_p \) is the cumulative production in MSCF, \( t \) is time in day, \( D \) is the decline rate in 1/day and subscript \( i \) stands for the initial condition.

Transient flow equations in field units:
\[ \psi (r,t) = \psi_i \frac{1.422 q_{sc} T}{kh} P_D, \quad \eta = \frac{6.33k}{\phi \mu_c c_i}, \quad t_D = \frac{\eta t}{r_w^2} \]
\[ P_D = \frac{1}{2} (\ln t_D + 0.809) \quad \text{only if } t_D > 100, \]
\[ \psi(r, t) = \psi_i - \frac{1.422 q_g T}{kh} p_D \]

where \( \psi \) is the real gas pseudo pressure in psi/ft, \( \phi \) is porosity, \( t \) is time in day, \( t_0 \) is the dimensionless time, \( k \) is permeability in Darcy, \( h \) is formation thickness in ft, \( r \) is radius in ft, \( p \) is pressure in psia, \( c \) is the isothermal compressibility in psi\(^{-1}\), \( \mu \) is the gas viscosity in cP, \( T \) is temperature in R, \( S \) is skin factor, and \( p_D \) is the dimensionless pressure. The subscript \( i \) denotes the initial condition.

**Gas wells drawdown Test**

Slope of the semilog-plot: \( m = \frac{1637 q_g T}{kh} \), \( q_g \) is in MSCFD, \( T \) is \( ^° \)R, \( k \) in mD, \( h \) in ft.

Test skin factor: \( S' = 1.15 \left( \frac{\psi_i - \psi(\Delta t = 1 hr)}{|m|} - \log \left( \frac{k}{\phi \mu c_s r_w^2} \right) + 3.23 \right) \), where \( S' \) is the test skin factor, \( c \) is the gas isothermal compressibility in psi\(^{-1}\), \( \mu \) is the gas viscosity in cP, and \( \phi \) is porosity.

True skin factor: \( S' = S + Dq \), where \( D \) is the non-Darcy or turbulent factor in 1/MSCFD.

**Gas wells deliverability equation:**

\[ q = C(\overline{p}^2 - p_w^2)^n \] where \( \overline{p} \) is the average reservoir pressure, and \( p_w \) is the stabilized flowing wellbore pressure, \( q \) is the gas production rate, \( C \) is the coefficient of the equation in any consistent systems of unit and \( n \) is an exponent.

**Conversion Factors**

- 1 m\(^3\) = 6.28981 bbl \( \approx \) 35.3147 ft\(^3\)
- 1 acre = 43560 ft\(^2\)
- 1 ac-ft = 7758 bbl
- 1 Darcy = 9.869233 \times 10^{-13} \text{ m}^2
- 1 atm = 14.6959488 psig = 101.32500 kPa = 1.01325 bar
- 1 cP = 0.001 Pa-sec
- 1 m = 3.28084 ft \( \approx \) 39.3701 inch